Object Controlled Laser

6.101 Final Report

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1.1 Introduction

Sensors are used in a wide array of electronics systems. For example airlines depend greatly on many unique sensors to determine speed, altitude and angle of their airplanes. Ultrasound sensors, specifically, are growing in use as a good mechanism for determining distance from objects and in search applications. Ultrasound, similar to the echolocation that dolphins use to ‘see’ the world around them, is a system where a pulse is sent out by a transmitter and a receiver waits to see if the signal is recovered. The goal of this project is to create a system that uses ultrasound to determine the location of an object. The signal received by the ultrasound will then be used to drive two Servos that will move a laser to a specific point to match the location of the object in the plane. Each servo is driven by the same circuit which is described in the coming sections. The two sensors are then placed 90 degrees from each other to simultaneously track an object.

1.2 Transmitter Circuit

1.2.0 Overview

The transmitter circuit is responsible for driving the ultrasonic sensor. In general, the way the sensor works is that a short pulse is sent out from the sensor. That signal bounces off all the objects in the environment and then is read by the receiver sitting directly next to the transmitter. There are subtle intricacies with designing the pulsed signal. The length of the pulse must be chosen such that it is long enough to provide a strong enough return signal. Also, the delay between pulses must be long enough to ensure that individual pulses are not interfering with each other. The ultrasonic sensor requires a 24 kHz square wave input signal to transmit a signal. This 24 kHz, 50% duty cycle square wave is created using a LM555C. The pulsing of this 24 kHz square wave is created using an AND gate. This AND gate takes in the 24 kHz square wave and a 222 Hz, 10% duty cycle squarewave. This creates the signal that is outputted from the ultrasonic sensor.

1.2.1 Squarewave

A 24 kHz square wave is created using an LM555 timer chip configured as an astable oscillator. The astable oscillator is very useful in that you can create very precise and accurate square waves by adjusting resistor values. Figure 1 shows the configuration used to create the 24 kHz square wave. The duty cycle of this system was set to 50%. For a 555 Timer set up in astable operation the Frequency is set by:

$$f = 1.44/(C * (Ra + 2 * Rb)$$

and the Duty Cycle is set by:

$$DT = Rb/(Ra + 2 * Rb)$$

Solving this system of equations leads up to the resistor and capacitor values shown below.

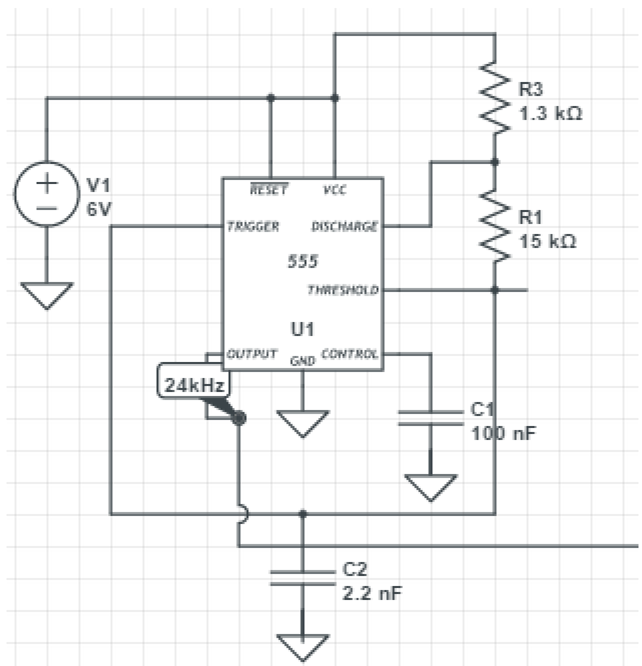

Figure 1- *A schematic of the circuit used to generate the 24 kHz, 50% Duty Cycle squarewave.*

1.2.2 Pulse Control Signal

A control signal is used to determine how long the 24 kHz pulse should be sent out and the timing between pulses. In order to determine the pulse width, I determined that about 12 cycles of the 24 kHz square wave was enough for the receiver to see a strong enough signal. A pulse length of 12 cycles at 24 kHz corresponds to a 450us pulse. A duty cycle of 10% was chosen to give sufficient time for the individual pulses to not interfere with each other. Putting these two design choices together resulted in a pulse control signal that is a 222 Hz square wave with a 10% duty cycle. Figure 2 shows the circuit used to generate this square wave. As mentioned above, when a 555 Timer set up in astable operation the Frequency is set by:

$$f = 1.44/(C * (Ra + 2 * Rb)$$

and the Duty Cycle is set by:

$$DT = Rb/(Ra + 2 * Rb)$$

Solving this system of equations leads up to the resistor and capacitor values shown below.

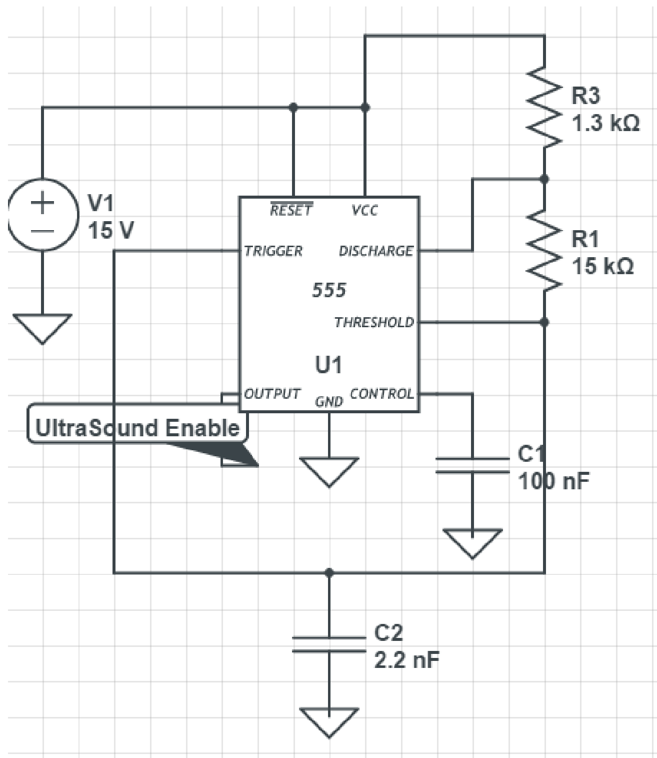

Figure 2- *A schematic of the pulse control signal. An LM555 is used to create a 222 Hz, 10% duty cycle squarewave.*

1.2.3 Complete Transmitter Circuit

The completed transmitter circuit runs the two signals mentioned above through an AND gate to create the final signal that is sent into the ultrasound. The outputted signal looks like a 24 kHz squarewave for the portion of the high portion of the Pulse Control signal and is a flat line for the low portion of the Pulse Control signal. Figure 3 shows the signal that is outputted from the ultrasound. Figure 4 shows the completed transmitter circuit.

Figure 3- *A mockup of the signal that enters the ultrasound. The AND gate takes in a 24 kHz, 50% DT square wave and a 222 Hz, 10% DT wave and outputs the signal in yellow. The pulse is 450 uS and the time between pulses is 4050uS.*

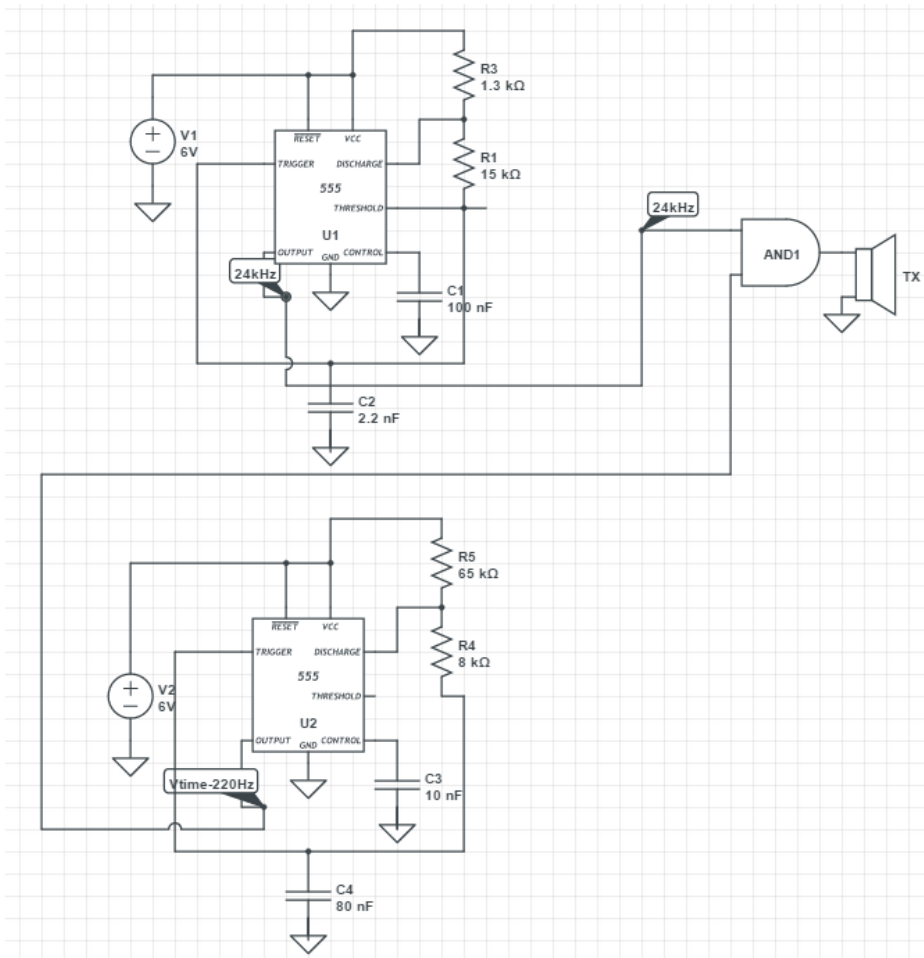

Figure 4- *A schematic of the entire transmitter circuit. A 24 kHz, 50% duty cycle square wave and a 222 Hz, 10% duty cycle squarewave are passed into an AND gate. The output of the AND gate goes into the transmitter.*

1.3 Receiver Circuit

1.3.0 Overview

Once the transmitter signal is sent, it will bounce off all the objects in the environment. In the case of the flat box we are using as the detected object, a majority of the signal is reflected back in the direction of the transmitter. For that reason we place the receiver directly next to the transmitter. The receiver creates a sine wave signal at 24 kHz whose phase and amplitude are proportional to the distance of the object. This is because the farther away the object is the less signal strength is returned to the receiver.

Once the signal is received, this circuit amplifies the signal, runs it through a peak detector, to find the maximum amplitude, and uses a digital inverter to create a square wave output. The square wave is used to drive the servos. Servos are controlled using different pulse-width square waves. We will carefully choose our inverter's threshold to correctly match the pulse widths that we require to turn the servos to the desired angles.

1.3.1 Output of Ultrasound

The output of the receiver, shown in green in Figure 5, is a sine wave. The amplitude of the sine wave is proportional to the distance of the object. This is an important property that we will exploit to drive the servos. The maximum magnitude of this sine wave ranges from the 20mV- 60mV peak to peak depending on where the object is located. An object nearly touching the sensors outputs a 60 mV maximum while an object about 2 feet away output a signal with a 20 mV maximum. A 7.5V source is run into the ground terminal of the ultrasound to give this signal more range and also increase the offset. In conclusion, the received signal is a sine wave centered at 7.5V with a range of 20-60 mV peak to peak.

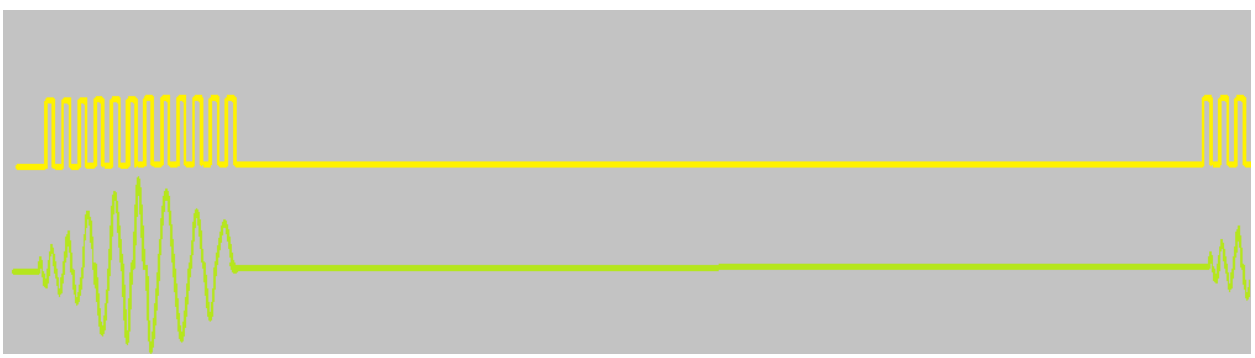

Figure 5- *Figure 5 shows a mockup of the scope shot where the yellow trace represents the signal outputted from the transmitter circuit and the green represents the signal outputted by the ultrasound receiver. The yellow output has a peak to peak voltage of 5V while the green trace's peak to peak is ~50mV.*

1.3.2 Amplifier

The returned signal is very heavily attenuated by the environment around it. This is especially true when the object is farther away. For this reason, I will need a gain of about 40 to bring the signal to noticeable difference in voltage peak. A non-inverting amplifier is used with resistor values of 120kΩ and 3.3kΩ were used to give a gain of 37. This amplifies the 20mV - 60mV peak to peak sine wave to 0.72V - 2.18V peak to peak. This leaves us with a sine wave still centered at 7.5V whose maximum ranges from 8.22V to 9.68V.

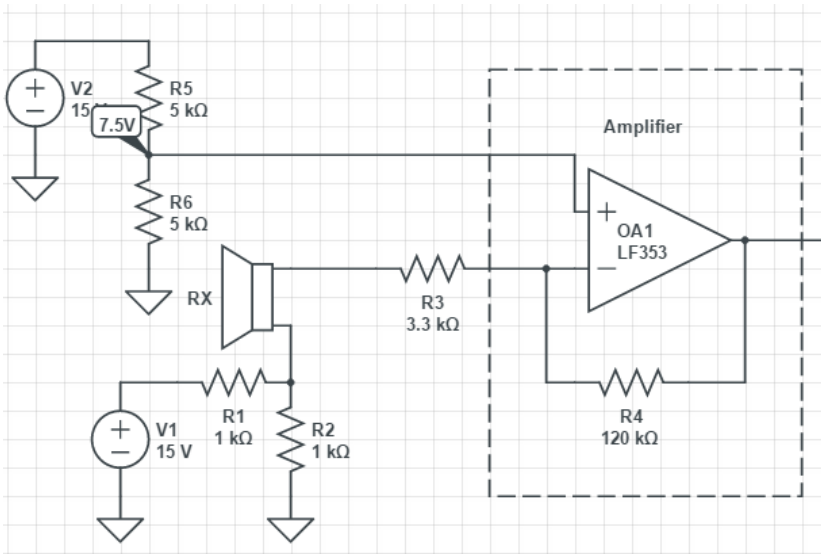

Figure 6- *A schematic of the first half of the receiver circuit. 7.5V offset is placed on the receiver. A non-inverting amplifier with a gain of about 40 is used to amplify the signal.*

1.3.3 Peak Detector

A peak detector circuit is a useful circuit in that it will charge a capacitor to the largest value present on the input. This can be very useful for a wide range of applications. In this circuit, the peak detector charges its capacitor to match the largest value on the amplified receive signal. Once the input signal starts to decrease, and eventually turn off, the capacitor discharges at a rate that we can set using the RC time constant. In later stages we will see how the discharge time is used to create the square waves that will drive our servo motors. Figure 7 shows a schematic of the peak detector circuit. The output of the peak detector is shown in figure 8.

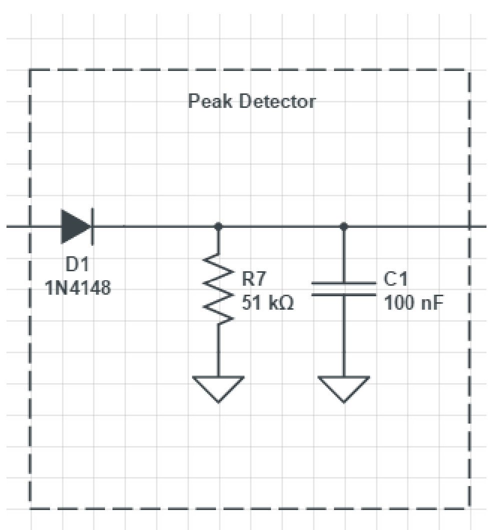

Figure 7- *Schematic of the peak detector circuit.*

Figure 8- *Mockup of the output of the peak detector. The received sine wave charges the capacitor and it then discharges through the resistor.*

1.3.4 Driving Servos

Servo Motors are controlled with a series of pulses. The length of those pulses turns the servo to a specific angle. For example, a pulse width of 2ms will the servo completely clockwise while a pulse width of 0.5ms will turn the servo completely counterclockwise. Any angle in between can be created using a pulse with a width between 0.5ms and 2ms. By creating a circuit that can create variable output pulses with widths between 0.5ms and 2ms we can move the servo to any desired angle. The last phase of the receiver circuit will take the output of the peak detector circuit and create a square wave with precisely the right width to drive the servos.

1.3.5 Square wave Creation

Using the knowledge of how servo motors are driven, we can exploit the peak detector's capacitor to create the square waves we need to drive the servos. A couple of important facts to keep in mind from the peak detector stage are that:

- The maximum value of the peak detector changes proportionally to the distance of the object.
- The capacitor discharges through the resistor with the same time constant every time.This time constant = RC of the peak detector.

To exploit these facts, the peak detector signal is run through a comparator circuit to create a square wave. All that is needed is an appropriate threshold voltage for the comparator. The threshold voltage must be chosen such that when the object is closest to the sensor the square wave pulse width is approximately 1.5 - 2 mS. This will turn the servo motor almost completely clockwise. In a similar manner, the threshold voltage must be chosen such that when the object is about 2 feet away from the sensors the peak detector's capacitor voltage remains above the threshold for approximately 0.5-0.9mS. Visual inspection showed me that that threshold voltage is 8.7V. In order to create the clean output square wave I wanted to use an inverter to create the square wave. The inverter has a VIh of 2.7V so in order to bring my signal down to the required voltage level I run the output of the peak detector into a 6V subtractor circuit. Figure 9 shows the complete second half of the circuit. The output of this circuit is a 0.8ms - 1.8ms width pulse that is used to drive the servos.

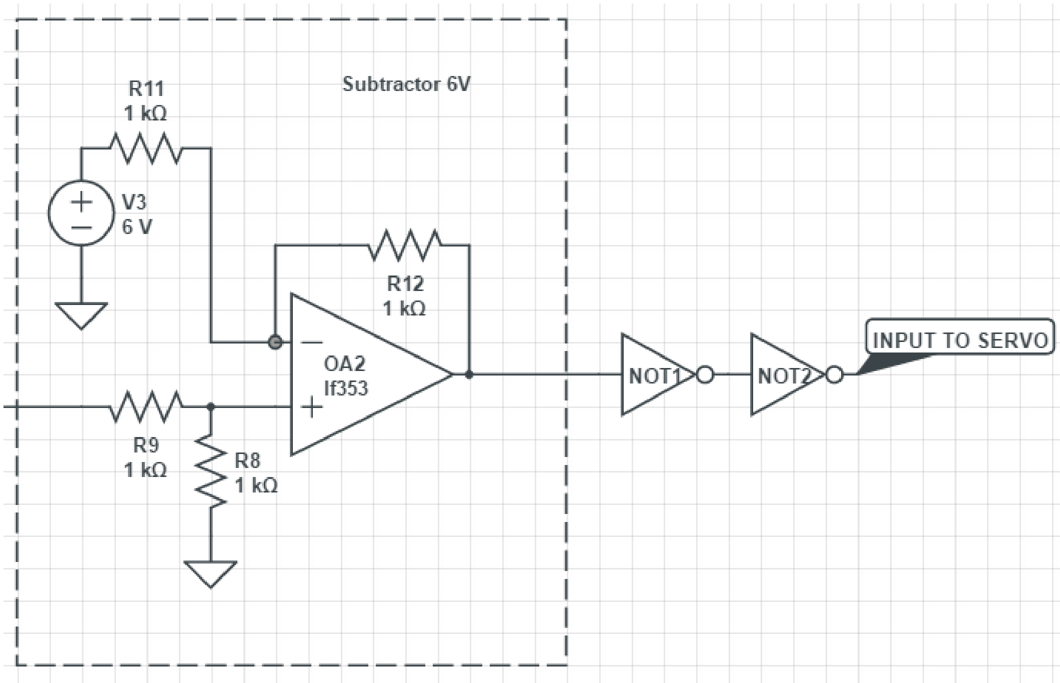

Figure 9- *A schematic of the second half of the receiver's circuit. The output of a peak detector is subtracted by 6V and then inverted twice to create the square wave that drives the servos. The square waves range from 0.8 mS- 1.8mS widths.*

1.3.6 Complete Circuit

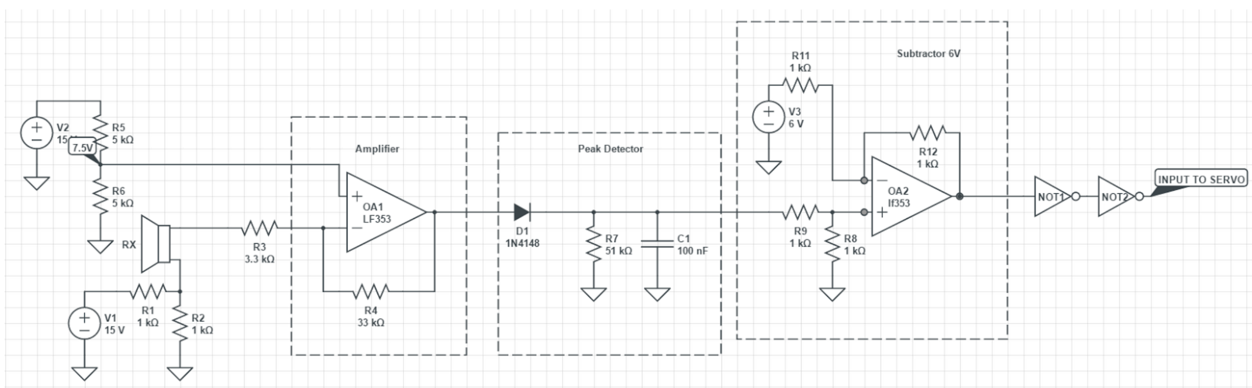

Figure 10- *A schematic of the complete receiver circuit that takes in a sine wave from the receiving ultrasound and outputs a square wave that drives the servo motors.*

1.4 Two axes

The complete circuits shown in figures 4 and 10 are duplicated so that there is one for each axis of rotation. The two sets of ultrasounds are placed 90 degrees from each other. Each ultrasound sensor set drives one Servo. The Servos are mounted on each other such that one servo controls the X-axis and the other controls the Y-axis. A laser is mounted on the second servo. Once power is turned on, an object can be placed in the line of sight of both ultrasounds. As you move the object across the plane, the servos respond to the position of the object.

1.5 Conclusion

1.5.0- Summary

Overall, I was pleased with the way the circuit responded to the environment. Ultrasound sensors are known for their natural buggy nature because of all the interference with the world around them. This presents for an interesting problem when driving motors with them. In the end, we were able to cleanly drive the motors with the ultrasonic sensors when run independently. As we moved a box towards and away from the sensors the servo cleanly rotated clockwise and then counter clockwise. When placing both sets of ultrasounds flat on the table top we were able to get a clean reaction from the servos as we moved the boxes up and down. When we placed the ultrasonic sensors 90 degrees from each other there was some clear interference between the two sets. It was also difficult to hold an object steady in their line of sight. A very large object is required to accurately block the interference from the other set of sensors.

1.5.1- Lessons Learned

This being one of my first large independent analog circuit project, I really learned the importance of modularizing a system. Throughout the project, I knew my end result was the variable width square wave but it took a series of phases to get to it. As I progressed through the stages altering the signal to be more and more useful, I learned many different techniques for modifying analog signals. I spent a good amount of time tinkering with circuits that did not even make my final design. For example, I created a sample and hold circuit to sample the peak detector’s output voltage because I was worried about the noise on that signal. I also created a circuit using a 555 timer that created a variable width square wave from a reference voltage. I had originally intended on averaging the output of the peak detector and running that into this Voltage controlled Oscillator but I was able to bypass that whole process by using the inverter circuit.

1.5.2- Further Improvements

Moving forward it would be interesting to research ways to get rid of the interference between the two axes. Placing the ultrasounds 90 degrees from each other produced a very noisy output signal. I would experiment with different timing schemes for outputting the signals of each ultrasound. If the different receivers are in an off state while the other is transmitting maybe there will be less interference.

1.6 References

References

555 Timer Datasheet: http://www.ti.com/lit/ds/symlink/lm555.pdf
How servos work: https://www.servocity.com/html/how_do_servos_work_.html#.VSIUJvnF9gk
74LS04 Inverter: http://www.futurlec.com/74LS/74LS04.shtml
LF353 Op Amp- http://www.ti.com/lit/ds/symlink/lf353-n.pdf
1n4148 Diode- http://www.vishay.com/docs/81857/1n4148.pdf
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